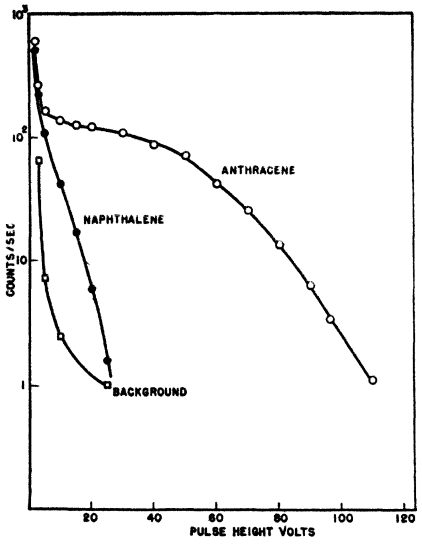

FIG. 2. Alpha-particles of Po.

pointed out by H. Kallman[1] and verified by M. Deutsch.[2] The substance most used by these authors is naphthalene, but both authors have suggested anthracene as a possible alternative.

In this laboratory we have prepared some transparent crystalline slabs of both materials, and their behavior as scintillation counters has been compared. It was found that it was more difficult to prepare satisfactory anthracene samples, but that these performed much better than naphthalene. Both kinds of samples were prepared by slow cooling of the melted materials. Anthracene had to be previously purified by sublimation and crystallization from hot benzene, and had to be melted in an atmosphere of nitrogen or argon. In this way clear pieces which appeared to be single crystals as large as $4\times5\times1$ cm could be obtained.

For the comparison the samples were placed as close as possible to the window of a 1P21 photo-multiplier tube operating at about 60 volts per stage. The tube and crystal were kept at room temperature. The pulses were amplified by a wide band linear amplifier[3] equipped with a pulse height selector with which one could conveniently study the size of the pulses.

Using samples of roughly the same size, it was found that gamma-rays from Co^{60} produced pulses about three times larger in anthracene than in naphthalene. The counting rate against pulse height selector setting is shown in Fig. 1. Extrapolating the counting rate to zero pulse height, the two materials give nearly the same number of counts, which is in agreement with Deutsch's finding that in these conditions we have 100 percent efficiency for the secondary electrons. However, if one sets the pulse height selector to admit only 10 background counts/sec., the anthracene is 93 percent efficient and the naphthalene only 63 percent. Raising still more the pulse height selector setting, it is possible to have both a high efficiency and a low background when anthracene is used.

Some experiments with C^{14}, emitting beta-rays of 154-kev maximum energy, proved that anthracene responds to electrons of this energy with about the same efficiency as a thin mica window Geiger counter.

Although Kallmann states that he was unable to count alpha-particles with his equipment when using scintillations from naphthalene, we could detect Po alpha-particles both with naphthalene and anthracene. Figure 2 shows the pulse height distribution for the two materials; it is evident that the pulses from anthracene are about five times larger. The extrapolated counting rate was the same as that found with the same source in an argon ionization chamber.

It seemed reasonable to expect that this system would count the recoil protons produced by fast neutrons, and some absorption experiments in Pb were carried out using a Po-α-Be neutron source. The absorption coefficient of Pb for the radiation responsible for most of the counts was 0.118 cm^{-1}. This value is much too small for gamma-rays of any energy and is in fairly good agreement with what could be expected for fast neutrons.

The neutrons produce very large pulses, some of which are two times as large as the largest pulses produced by Co^{60} gamma-rays. For an anthracene sample 1 cm thick a rough calculation shows that about 10 percent of the fast neutrons striking the anthracene are counted.

* This document is based on work performed under Contract Number W-35-058 eng-71 for the Atomic Energy Project at Oak Ridge National Laboratory.

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[2] Martin Deutsch, M.I.T. Tech. Rep. No. 3.
[3] W. H. Jordan and P. R. Bell, Rev. Sci. Inst. 15, 703 (1947).

Nuclear Reactions of Arsenic with 190-Mev Deuterons

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BOMBARDMENT of thin targets of pure arsenic ($_{33}As^{75}$) with 190-Mev deuterons has led to the observation of nuclear reactions in which some of the product nuclei are more than 20 mass units lighter than the target nucleus. Identification of these and of other reaction products was made by chemical separation of the various radio-isotopes into elemental fractions, followed by an investigation of the radiations associated with each fraction.

The gross rate of decay of the radio-isotopes in each elemental fraction was determined with argon-filled (10 cm pressure) Geiger-Müller counting tubes of the thin window type (*ca.* 3 mg/cm^2 of mica). The half-lives obtained from the resolved decay curves formed the chief basis for identification of known isotopes. In those cases in which sufficient activity was available, samples were placed in a crude beta-ray spectrometer and tested for positive or negative beta-particles.

Most of the radiations observed could be assigned to known isotopes; these isotopes are listed in Table I. The identifications of Zn^{72}, Cu^{60}, Ni^{57}, and Co^{55} are uncertain as they are based on half-lives obtained with low accuracy as a result of the high level of accompanying activities. The assignments of Mn^{52} and Cr^{51} are based on reliable half-life determinations from measurements of a small amount of activity in the manganese and chromium fractions. The identification of the remaining isotopes is beyond doubt.

Several new radioactivities have been observed. Mass assignments have been made by demonstration of the following decay chains.

(a) $\underset{\text{(new) 9.5 d}}{Se^{72}} \xrightarrow{K} \underset{\text{(known) 26 hr.}}{As^{72}} \xrightarrow{\beta^+} Ge^{72}$,

(b) $\underset{\text{(new) 44 m}}{Se^{71}} \xrightarrow{\beta^+} \underset{\text{(new) 52 m}}{As^{71}} \xrightarrow{\beta^+} \underset{\text{(known) 40 hr.}}{Ge^{71}} \xrightarrow{\beta^+} Ga^{71}$,

(c) $\underset{\text{(unassigned) (1) 250 d}}{Ge^{68}} \xrightarrow{K} \underset{\text{(known) 68 m}}{Ga^{68}} \xrightarrow{\beta^+} Zn^{68}$.

"Milkings" of As^{73} from Se^{73} (β^+, 6.7 hour) have failed to produce measurable activity. This behavior is consistent with the assignment of the 100-day activity[2] to As^{73}.

Rough values for the yields of the isotopes have been determined. The figures presented in the table are ratios relative to the yield of As^{72}, and are average figures for several bombardments. The calculations are only approximate because of errors due to (a) self-absorption and absorption in air, (b) scattering, and (c) unknown counting efficiencies for orbital electron capturing isotopes.

In the column "reaction Δ" are given the differences in mass and charge between the product isotopes and the target nucleus, $_{33}As^{75}$. Because of the time required for chemical separations, no activities of less than about 15 minutes half-life would have been seen. Isotopes of half-life greater than about 200 days formed in yield less than 0.05 that of As^{72} would not have been detected.

Salient features of the data are: (a) the low yield of selenium isotopes as compared with arsenic isotopes, (b) the predominance of neutron deficient isotopes from selenium to gallium, and (c) the presence of isotopes containing an excess of neutrons, of the elements below zinc in yields comparable to those of the neutron deficient isotopes.

It will be noted that over 80 percent of the reactions observed produce isotopes within 8 mass units of As^{75}. Since these reactions require excitation of less than ~75 Mev, it appears that the high energy deuteron gives up only part of its energy in most of the reactions. This behavior is consistent with the picture of high energy nuclear reactions recently proposed by Serber.[3]

This work was performed under Contract No. W-7405-eng-48, with the Atomic Energy Commission in connection with the Radiation Laboratory of the University of California, Berkeley, California. The bombardments were conducted by Dr. Duane Sewell and the 184-inch cyclotron group.

TABLE I. Isotopes produced by $_{33}As^{75}$+200 Mev D^+.

Isotope	Type of radiation[a]	Half-life Observed	Half-life Literature[b]	Yield[c] Rel As^{72} [d]	Reaction Δ ΔZ	Reaction Δ ΔA
$_{34}Se^{75}$	(K, γ, e^-)	120 d	115 d[e]	0.11 (5%)	+1	+0
$_{34}Se^{73}$	β^+	6.7 h	—	0.09	+1	−2
$_{34}Se^{72}$	K	9.5 d	—	0.1 (100%)	+1	−3
$_{34}Se^{71}$	β^+	44 m	—	0.01	+1	−4
$_{33}As^{74}$	β^-, β^+, γ	19.0 d	16 d	1.1	0	−1
$_{33}As^{72}$	β^+	26 h	26 h	1.00	0	−3
$_{33}As^{71}$	β^+	52 m	—	0.3	0	−4
$_{32}Ge^{71}$	β^+, K	38 h 11.4 d	40 h 11 d	2 ~2 (3%)	−1	−4
$_{32}Ge^{68}$	K	250 d	195 d	≈5 (100%)	−1	−6
$_{31}Ga^{68}$	β^+	68 m	68 m	0.2	−2	−7
$_{31}Ga^{67}$	K, γ, e^-	83 h	83 h	~3 (5%)	−2	−8
$_{31}Ga^{66}$	β^+	10 h	9.4 h	~0.1	−2	−9
$_{30}Zn^{72}$	(β^-, γ)	~50 h	49 h[f]	≤0.001	−3	−3
$_{30}Zn^{69}$	$(\beta^-, \text{I. T.}, \gamma)$	51 m 14 h	57 m 13.8 h	0.07 0.05	−3	−6
$_{29}Cu^{67}$	β^-	61 h	56 h[g]	0.02	−4	−8
$_{29}Cu^{64}$	$(\beta^-, \beta^+, K, \gamma)$	13 h	12.8 h	0.1	−4	−11
$_{29}Cu^{61}$	(β^+, K)	3.3 h	3.4 h	0.1 (100%)	−4	−14
$_{29}Cu^{60}$	(β^+)	~20 m	24.5 m[h]	0.06	−4	−15
$_{28}Ni^{66}$	β^-	56 h	56 h[g]	0.002	−5	−9
$_{28}Ni^{65}$	(β^-, γ)	2.6 h	2.6 h	0.001	−5	−10
$_{28}Ni^{57}$	β^+	34 h	36 h	0.0002	−5	−18
$_{27}Co^{61}$	(β^-)	1.8 h	1.75 h[i]	0.003	−6	−14
$_{27}Co^{56-58}$	(β^+, γ, K)	~80 d	72 d	0.06 (35%)	−6	−19 −17
$_{27}Co^{55}$	β^+, γ	~16 h	18.2 h	0.003	−6	−20
$_{26}Fe^{59}$	(β^-, γ)	43 d	47 d	0.005	−7	−16
$_{25}Mn^{56}$	(β^-, γ)	2.6 h	2.59 h	0.002	−8	−19
$_{25}Mn^{52}$	(β^+, γ, K)	6 d	6.5 d	0.0002 (40%)	−8	−23
$_{24}Cr^{51}$	(K, γ, e^-)	26 d	26.5 d	0.005 (5%)	−9	−24

[a] Parentheses signify identification based on half-life determination only.
[b] G. T. Seaborg, Rev. Mod. Phys. 16, 1 (1944).
[c] The yield of As^{72} corresponds to a cross section of about 0.02×10^{-24} cm^2.
[d] Parenthesized figures signify assumed counting efficiencies.
[e] H. N. Friedlander, L. Seren, and S. H. Turkel, Phys. Rev. 72, 23 (1947).
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The Neutron-Proton Scattering Formula*

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IN the letter of Flügge and Hückel[1] it was pointed out that the neutron-proton scattering cross sections may be obtained for low energies of the incident neutron from an expression similar to the Breit-Wigner formula. It was stated that the "energy of the singlet level"—the E' ($=\hbar^2\kappa'^2/M$) of their formula—required to provide a fit to observed low energy neutron-proton cross sections is about 1.5 Mev. In the concluding remarks of their letter, Flügge and Hückel imply that the deviation of this value of E' from the "energy of the singlet level" as usually given, $\epsilon' \sim 0.1$ Mev, has important consequences for other problems.